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(54) High strength and high ductility TiAL-based intermetallic compound and process for producing the same.

(57) A high strength and high ductility TiA1-based intermetallic compound includes a content of aluminum in a range represented by 42.0 atom % ≦ A1 ≦ 50.0 atom %, a content of vanadium in a range represented by 1.0 atom % ≦ V ≦ 3.0 atom %, a content of niobium in a range represented by 1.0 atom % ≦ Nb ≦ 10.0 atom %, a content of boron in a range represented by 0.03 atom % ≦ B ≦ 2.2 atom %, and the balance of titanium and unavoidable impurities. A product of the TiA1-based intermetallic compound is formed by only casting or casting followed by a homogenizing thermal treatment.

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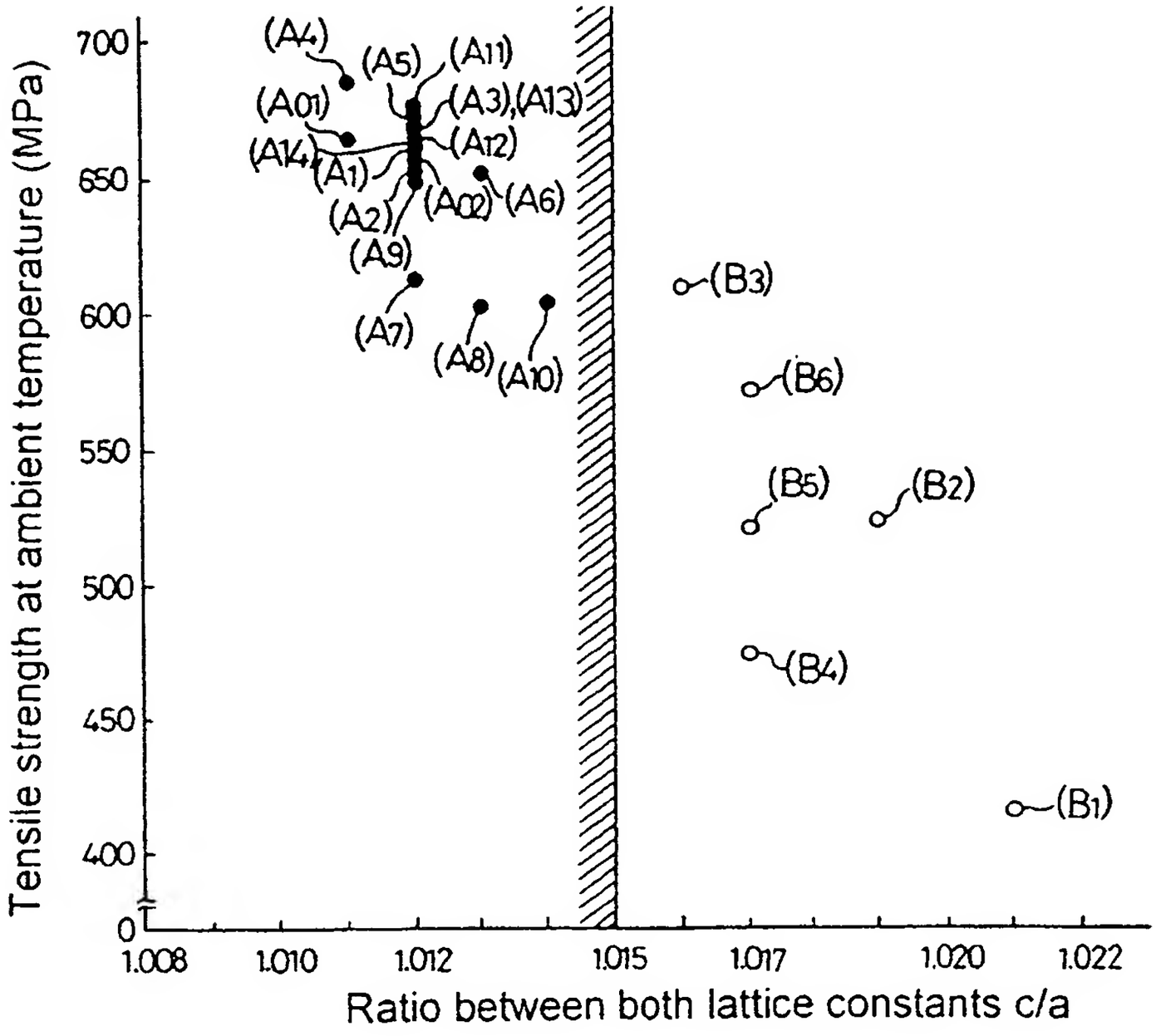
FIG.3


Tensile strength at ambient temperature (MPa)
700
650
600
550
500
450
400
0
1.008
1.010
1.012
1.015
1.017
1.020
1.022
Ratio between both lattice constants c/a
(A4)
(A5)
(A11)
(A01)
(A3),(A13)
(A14)
(A12)
(A1)
(A2)
(A02)
(A6)
(A9)
(A7)
(A8)
(A10)
(B3)
(B6)
(B5)
(B2)
(B4)
(B1)

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a high strength and high ductility TiAl-based intermetallic compound and to a process for producing the same.

DESCRIPTION OF THE PRIOR ART

TiA1-based intermetallic compound is excellent as a component material for a rotating part in an engine because it is lightweight and has an excellent heat-resistance. However, normally it is very brittle and hence, an improvement in this respect is desired.

In order to provide both the strength and the ductility at ambient temperature, various TiA1-based intermetallic compounds have been conventionally proposed. For example, there are known TiA1-based intermetallic compounds produced by subjecting an ingot containing niobium and boron, or vanadium and boron added thereto to an isothermal forging (see Japanese Patent Application Laid-Open No. 298127/89).

However, such a prior art TiA1-based intermetallic compound has relatively high ductility and strength at ambient temperature, because it is produced through isothermal forging at a high temperature, but such compounds have not yet been put into practical use. In addition, the prior art TiA1-based intermetallic compounds suffer from a problem that it is absolutely necessary to conduct the isothermal forging at a high temperature after the casting, thereby bringing about increases in the number of manufacture steps and in equipment cost. Therefore, an increase in manufacture cost of the Tia1 -based intermetallic compound is inevitable and moreover, the degree of freedom of the shape of the products made from the intermetallic compounds is low.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a TiA1-based intermetallic compound of the type described above, wherein, by specifying the types and contents of added elements, a high level of both strength and ductility at ambient temperature can be provided either by only casting or by a homogenizing thermal treatment after the casting, whereby a reduction in manufacture cost and an increase in the degree of freedom of the shape are realized.

To achieve the above object, according to the present invention, there is provided a high strength and high ductility TiA1-based intermetallic compound comprising a content of aluminum (A1) in a range represented by 42.0 atom % $\leq$ A1 $\leq$ 50.0 atom %, a content of vanadium (V) in a range represented by 1.0 atom % $\leq$ V $\leq$ 3.0 atom %, a content of niobium (Nb) in a range represented by 1.0 atom % $\leq$ Nb $\leq$ 10.0 atom %, a content of boron (B) in a range represented by 0.03 atom % $\leq$ B $\leq$ 2.2 atom %, and the balance of titanium and unavoidable impurities.

Another object of this invention is to provide such a TiA1-based intermetallic compound with the aluminum content in the above range, whereby the metallographic texture of the TiA1-based intermetallic compound, after the casting or after a homogenizing thermal treatment following the casting, is composed of a $L1_0$ type γ phase (TiA1 phase), an α 2 phase (Ti_3A1 phase) and a very small amount of an intermetallic compound phase. In this case, the main phase is the $L1_0$ type γ phase, and the volume fraction Vf thereof reaches a value equal to or more than 80% (Vf $\geq$ 80%). Such a metallographic texture of a two\phase structure is effective for enhancing the strength and ductility at ambient temperature for the TiA1-based intermetallic compound.

Another object of this invention is to provide such a TiA1-based intermetallic compound with vanadium, niobium and boron all included with their contents in the above ranges, whereby the metallographic texture of the TiA1-based intermetallic compound, after the casting or after the homogenizing thermal treatment following the casting, assumes a finely divided form and has a relatively high hardness. The ambient temperature strength of the TiA1-based intermetallic compound is considerably enhanced by such effects of aluminum as well as vanadium, niobium and boron.

Another object of this invention is to provided such a TiA1-based intermetallic compound with the TiA1-based intermetallic compound being produced by only casting or by a homogenizing thermal treatment following the casting. This provides advantages of a relatively low manufacture cost and a high degree of freedom of the shape of the products made of the TiA1-based intermetallic compound.

The above and other objects, features and advantages of the invention will become apparent from the following description of a preferred embodiment taken in conjunction with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view illustrating a crystal structure of an $L1_0$ type γ phase;
Fig. 2 is an X-ray diffraction pattern for a TiA1-based intermetallic compound of this invention;
Fig. 3 is a graph illustrating the relationship between the tensile strength at ambient temperature and the ratio c/a between both lattice constants of examples of compounds of this invention and comparative examples; and
Fig. 4 is a graph illustrating the relationship between the elongation at ambient temperature and the ratio c/a between both lattice constants of examples of compounds of this invention and comparative examples.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Blanks of various compositions were prepared which included a content of aluminum (A1) in a range represented by 42.0 atom % ≦ A1 ≦ 50.0 atom %, a content of vanadium (V) in a range represented by 1.0 atom % ≦ V ≦ 3.0 atom %, a content of niobium (Nb) in a range represented by 1.0 atom % ≦ Nb ≦ 10.0 atom %, a content of boron (B) in a range represented by 0.03 atom % ≦ B ≦ 2.2 atom %, and the balance of titanium and unavoidable impurities. The blanks were melted under an argon atmosphere by use of a non-consumable arc melting furnace. And the molten metals were poured into a water-cooled copper casting mold to produce ingots having a diameter of 14 mm and a length of 100 mm.

Thereafter, the ingots were subjected to a homogenizing thermal treatment under conditions of 1,200 °C for 3 hours in a vacuum to provide various TiA1-based intermetallic compounds, identified by (A_1) to (A_{14}), as examples of embodiments of the present invention.

Table 1 shows the compositions and the volume fractions Vf of $L1_0$ type γ phases for the TiA1-based intermetallic compounds (A_1) to (A_{14}), and for two TiA1-based intermetallic compounds (A_{01}) and (A_{02}) which were produced without the homogenizing thermal treatment. The TiA1-based intermetallic compounds (A_{01}) and (A_{02}) correspond in content to the ingots for the TiA1-based intermetallic compounds (A_4) and (A_5). Unavoidable impurities are contained in the "balance" in the Ti column in Table 1.

Table 1

TiA1-based intermetallic compound	Chemical constituents (atom%)					$L1_0$ type γ phase Vf (%)
	A1	V	Nb	B	Ti	
(A_{11})	42.0	3.0	2.0	1.0	Balance	80
(A_2)	45.0	1.0	1.0	0.5	Balance	84
(A_3)	45.0	1.0	3.0	1.0	Balance	85
(A_4)	45.0	2.0	2.0	1.3	Balance	86
(A_5)	45.0	2.0	3.0	1.5	Balance	85
(A_6)	45.0	3.0	2.0	2.0	Balance	85
(A_7)	49.0	3.0	2.0	1.0	Balance	94
(A_8)	46.0	1.0	10.0	0.7	Balance	85
(A_9)	45.0	2.0	8.0	1.2	Balance	83
(A_{10})	50.0	1.5	2.0	1.0	Balance	98
(A_{11})	46.0	2.0	2.0	0.3	Balance	90
(A_{12})	46.0	2.0	2.0	2.2	Balance	91
(A_{13})	45.0	2.0	2.0	0.03	Balance	90
(A_{14})	46.0	2.0	2.0	0.1	Balance	90
(A_{01})	45.0	2.0	2.0	1.3	Balance	82
(A_{02})	45.0	2.0	3.0	1.5	Balance	81

For comparison, blanks of various compositions including aluminum as a requisite chemical constituent, vanadium, chromium, niobium and boron as optional chemical constituents, and the balance of Ti and unavoidable impurities were prepared and then subjected sequentially to melting, casting and homogenizing thermal treatments to provide various TiA1-based intermetallic compounds (B_1) to (B_6) as comparative examples. The ingots of TiA1-based intermetallic compounds (B_1) to (B_6) had the same size as those in the examples of the embodiment, i.e., a diameter of 14 mm and a length of 100 mm.

Table 2 shows the compositions and the volume fractions Vf of $L1_0$ type γ phases for the TiA1-based intermetallic compounds (B_1) to (B_6). Unavoidable impurities are contained in the "balance" in the Ti column in Table 2.

Table 2

TiA1-based intermetallic compound	Chemical constituents (atom %)						$L1_0$ type γ phase Vf (%)
	A1	V	Cr	Nb	B	Ti	
(B_1)	50.0	-	-	-	-	Balance	98
(B_2)	48.0	2.5	-	-	-	Balance	90
(B_3)	48.0	-	2.0	4.0	1.0	Balance	88
(B_4)	48.0	-	-	2.0	-	Balance	92
(B_5)	48.0	2.0	-	-	0.5	Balance	89
(B_6)	48.0	-	-	2.5	1.0	Balance	92

The TiA1-based intermetallic compounds (A_1) to (A_{14}), (A_{01}), (A_{02}), (B_1) to (B_6) were subjected to an X-ray diffraction to determine a ratio c/a between lattice constants "a" and "c" in a crystal structure of $L1_0$ type γ phase.

The crystal structure of $L1_0$ γ phase is shown in Fig. 1 and is a face-centered tetragonal system. The ratio c/a is determined from a ratio d_2/d_1 between a spacing d_1 of planes specified by a reflection from a plane (200) indicating the lattice constant "a" on an axis "a", and a spacing d_2 of planes specified by a reflection from a plane (002) indicating the lattice constant "c" on an axis "c" in an X-ray diffraction pattern.

Test pieces were fabricated according to an ASTM E8 Specification from the TiA1-based intermetallic compounds (A_1) to (A_{14}), (A_{01}), (A_{02}) and (B_1) to (B_6). These test pieces were used to conduct a tensile test under a condition of a rate of strain of 0.3%/min (constant) at ambient temperature in the atmosphere to determine the tensile strength and the elongation at ambient temperature for the TiA1-based intermetallic compounds (A_1) to (A_{14}), (A_{01}), (A_{02}), and (B_1) to (B_6).

Table 3 shows the ratio c/a between both the lattice constants and the tensile strength and elongation at ambient temperature for the TiA1-based intermetallic compounds (A_1) to (A_{14}), (A_{01}), (A_{02}) and (B_1) to (B_6).

Table 3

TiA-1 based intermetallic compound	Ratio c/a between lattice constants	Tensile strength at ambient temperature (MPa)	Elongation at ambient temperature (%)
(A_1)	1.012	661	1.5
(A_2)	1.012.	654	1.3
(A_3)	1.012	670	1.4
(A_4)	1.011	685	2.0
(A_5)	1.012	671	1.9
(A_6)	1.013	653	1.5
(A_7)	1.012	613	1.3
(A_8)	1.013	601	1.0
(A_9)	1.012	650	1.2
(A_{10})	1.014	603	1.0
(A_{11})	1.012	672	1.2
(A_{12})	1.012	668	1.5
(A_{13})	1.012	670	1.5
(A_{14})	1.012	666	1.8
(A_{01})	1.011	665	1.8
(A_{02})	1.012	659	1.6
(B_1)	1.021	421	0.3
(B_2)	1.019	525	0.6
(B_3)	1.016	610	0.7
(B_4)	1.017	477	0.5
(B_5)	1.017	523	0.7
(B_6)	1.017	575	0.6

Fig. 2 shows an X-ray diffraction pattern for the TiA1-based intermetallic compound (A_4), wherein peaks of reflection from the (002) and (200) planes are observed.

Fig. 3 is a graph of the values taken from Table 3 and illustrating the relationship between the tensile strength at ambient temperature and the ratio ca between both the lattice constants. Fig. 4 is a graph of the

values taken from Table 3 and illustrating the relationship between the elongation at ambient temperature and the ratio c/a between both the lattice constants.

The TiA1-based intermetallic compounds (A_1) to (A_{14}), (A_{01}) and (A_{02}) as the examples of embodiments of the invention include the chemical constituent contents set within the above-described range. As apparent from Tables 1 and 3 and Figs. 3 and 4, each of the compounds has an excellent tensile strength and an excellent elongation at ambient temperature, as compared with the TiA1-based intermetallic compounds (B_1) to (B_6) as the comparative examples, due to the volume fraction Vf of $L1_0$ type γ phases equal to or more than 80% ($Vf \geqq 80\%$) and due to the lattice constants being approximately equal to each other, i.e. c/a approaches 1.0. Therefore, it is possible to provide high levels of both strength and ductility at ambient temperature.

Each of the TiA1-based intermetallic compounds (A_{01}) and (A_{02}) produced by only casting have slightly inferior tensile strength and elongation at ambient temperature, as compared with the TiA1-based intermetallic compounds (A_4) and (A_5) having the same composition and produced with the homogenizing thermal treatment, but have the substantially same ratio c/a between both the lattice constants.

In addition, it has been ascertained from various experiments that the ratio c/a between both the constants is preferably equal to or less than 1.015 ($c/a \leqq 1.015$), because, if the ratio c/a exceeds 1.015, the isotropy of TiA1 - γ is lost and both the strength and ductility are lowered. In this case, the ratio c/a between both the constants cannot be less than 1.0 ($c/a < 1.0$).

By comparison of the TiA1-based intermetallic compound (B_1) with the TiA1-based intermetallic compounds (B_2) and (B_4) in Tables 2 and 3 and Fig. 4, it can be seen that the ratio c/a between the lattice constants is reduced, and the elongation at ambient temperature is slightly increased, due to the addition of only vanadium or niobium.

The crystal structure of $L1_0$ type γ phase is of a face-centered tetragonal system, and between both lattice constants "a" and "c", a relation $a < c$ is established, that can result in problems of a low isotropy of the crystal structure and a reduced ambient temperature ductility of the TiA1-based intermetallic compound. However, with the addition of vanadium, niobium and boron in their respective contents set forth above, both the lattice constants a and c ni the $L1_0$ type γ phase crystal structure can be approximated to each other, thereby improving the isotropy of the $L1_0$ type γ phase crystal structure. Further, because the metallographic texture is formed into the two-phase structure, the ambient temperature ductility of the TiA1-based intermetallic compound can considerably be enhanced.

However, if the aluminum content is less than 42.0 atom %, the volume fraction of α_2 phase is too high, thereby bringing about a reduction in ambient temperature ductility of the TiA1-based intermetallic compound. On the other hand, if the aluminum content is more than 50.0 atom %, the volume fraction of α_2 phase is too low, thereby bringing about a reduction in ambient temperature strength of the TiA1-based intermetallic compound.

If the vanadium, niobium and boron contents are less than 1.0 atom %, less than 1.0 atom % and less than 0.03 atom %, respectively, it is impossible to achieve the approximation of both the lattice constants a and c to each other and hence, the considerable enhancement in ambient temperature ductility of the TiA1-based intermetallic compound cannot be achieved. If vanadium and niobium are added alone, the lattice constants are approximated to each other to a certain extent, but such extent is small, resulting in a low degree of enhancement in ambient temperature ductility of the TiA1-based intermetallic compound.

On the other hand, if the vanadium content is more than 3.0 atom %, the TiA1-based intermetallic compound is embrittled due to an increase in hardness of the matrix. If the niobium content is more than 10.0 atom %, the volume fraction Vf of brittle intermetallic compound phase is increased, thereby bringing about a reduction in ambient temperature ductility of the TiA1-based intermetallic compound. Further, if the boron content is more than 2.2 atom %, a course B-based intermetallic compound is precipitated, resulting in a reduced ambient temperature ductility of the TiA1-based intermetallic compound.

Claims

1. A high strength and high ductility of TiA1-based intermetallic compound comprising a content of aluminum (A1) in a range represented by 42.0 atom % $\leqq$ A1 $\leqq$ 50.0 atom %, a content of vanadium (V) in a range represented by 1.0 atom % $\leqq$ V $\leqq$ 3.0 atom %, a content of niobium (Nb) in a range represented by 1.0 atom % $\leqq$ Nb $\leqq$ 10.0 atom %, a content of boron (B) in a range represented by 0.03 atom % $\leqq$ B $\leqq$ 2.2 atom %, and the balance of titanium and unavoidable impurities.

2. A high strength and high ductility TiA1-based intermetallic compound according to claim 1, wherein the main phase is an $L1_0$ type γ phase, a ratio c/a between both lattice constants "a" and "c" in the crystal

structure o said $L1_0$ type γ phase being in a range represented by c/a ≦ 1.015.

3. A high strength and high ductility TiA1-based intermetallic compound according to claim 2, wherein relationship between both lattice constants is c/a > 1.0.

4. A high strength and high ductility TiA1-based intermetallic compound according to claim 1, wherein the main phase is an $L1_0$ type γ phase having a volume fraction percent equal to or greater than 80%.

5. A method for producing a high strength and high ductility TiAl-based intermetallic compound, comprising the steps of:

preparing a blank which includes a content of aluminum (Al) in a range represented by 42.0 atom % ≦ Al ≦ 50.0 atom %, a content of vanadium (V) in a range represented by 1.0 atom % ≦ V ≦ 3.0 atom %, a content of niobium (Nb) in a range represented by 1.0 atom % ≦ Nb ≦ 10.0 atom %, a content of boron (B) in a range represented by 0.03 atom % ≦ B ≦ 2.2 atom %, and the balance of titanium and unavoidable impurities;

melting said blank to provide a molten metal;

casting said molten metal to provide an ingot; and

subjecting said ingot to a homogenizing thermal treatment.

FIG.1

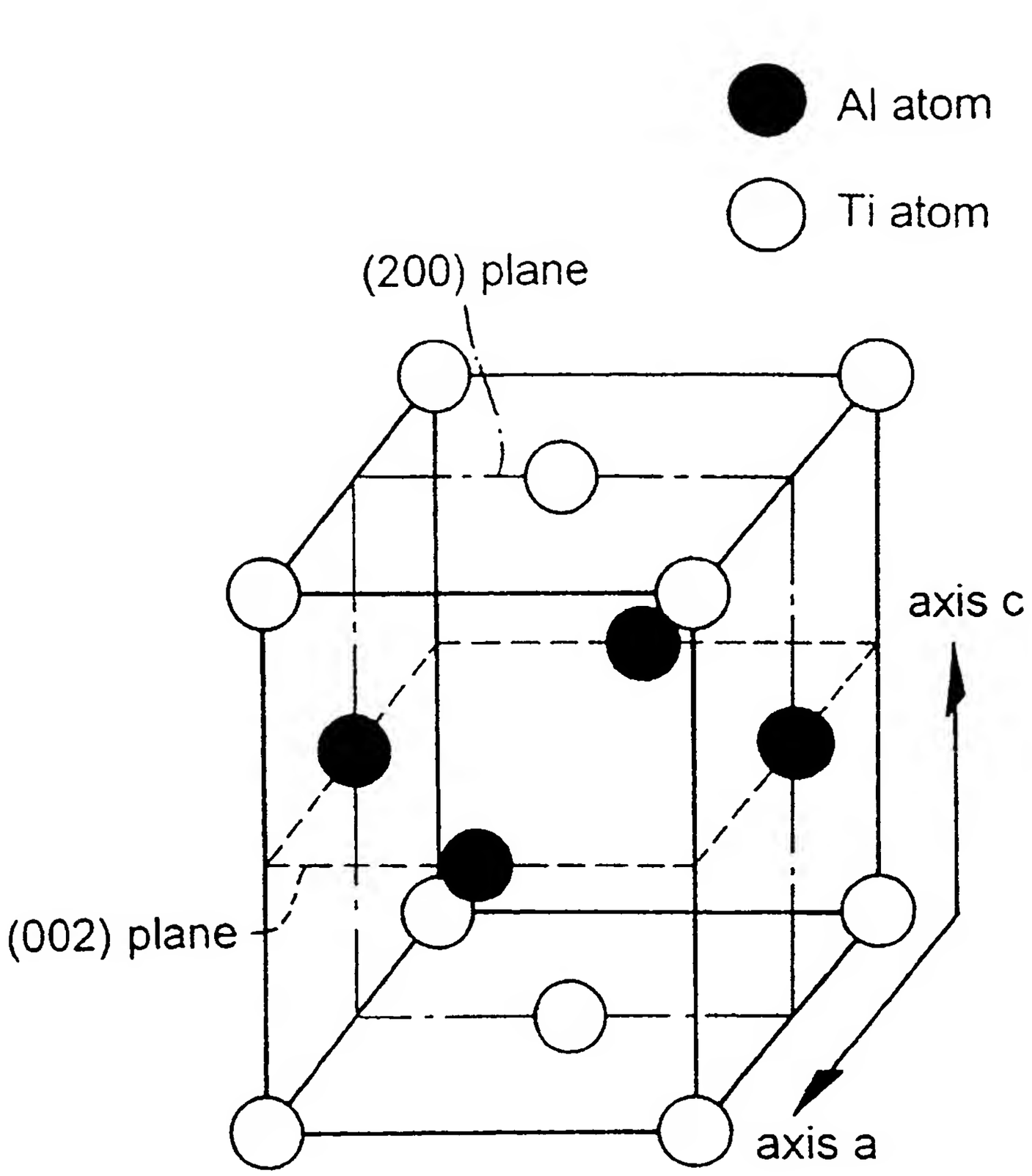


FIG.2

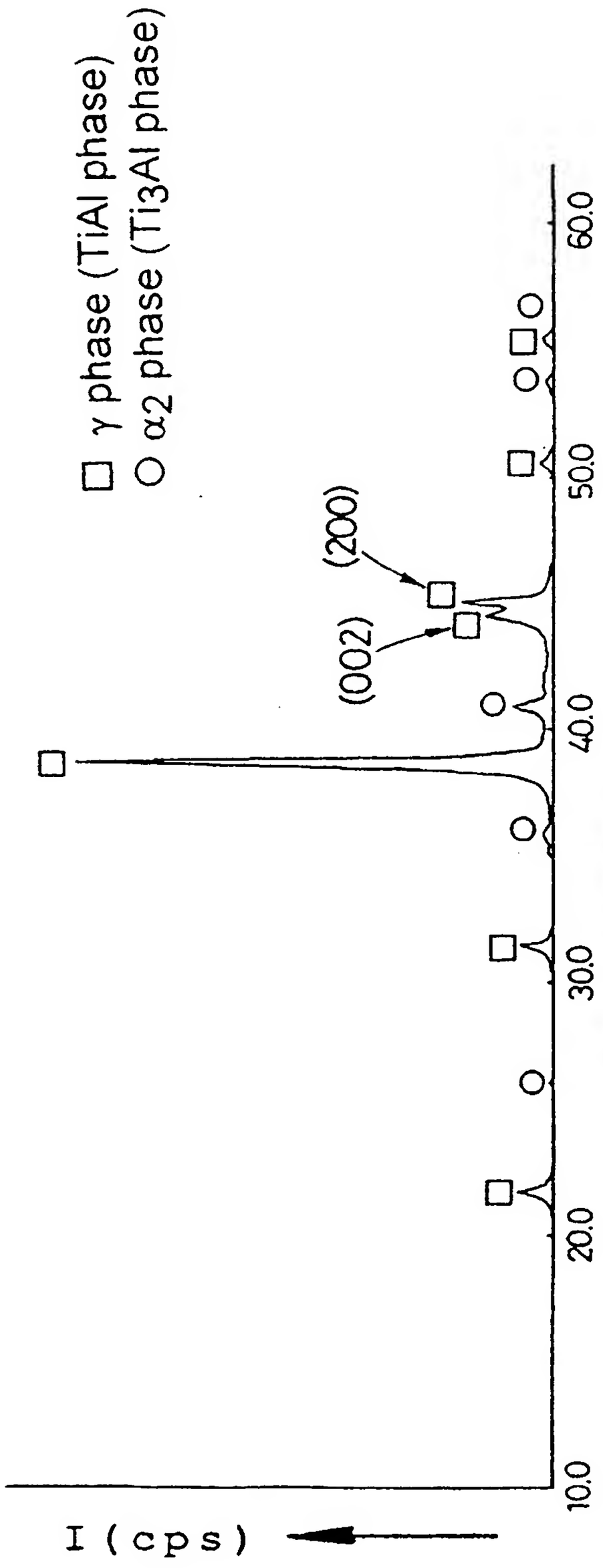
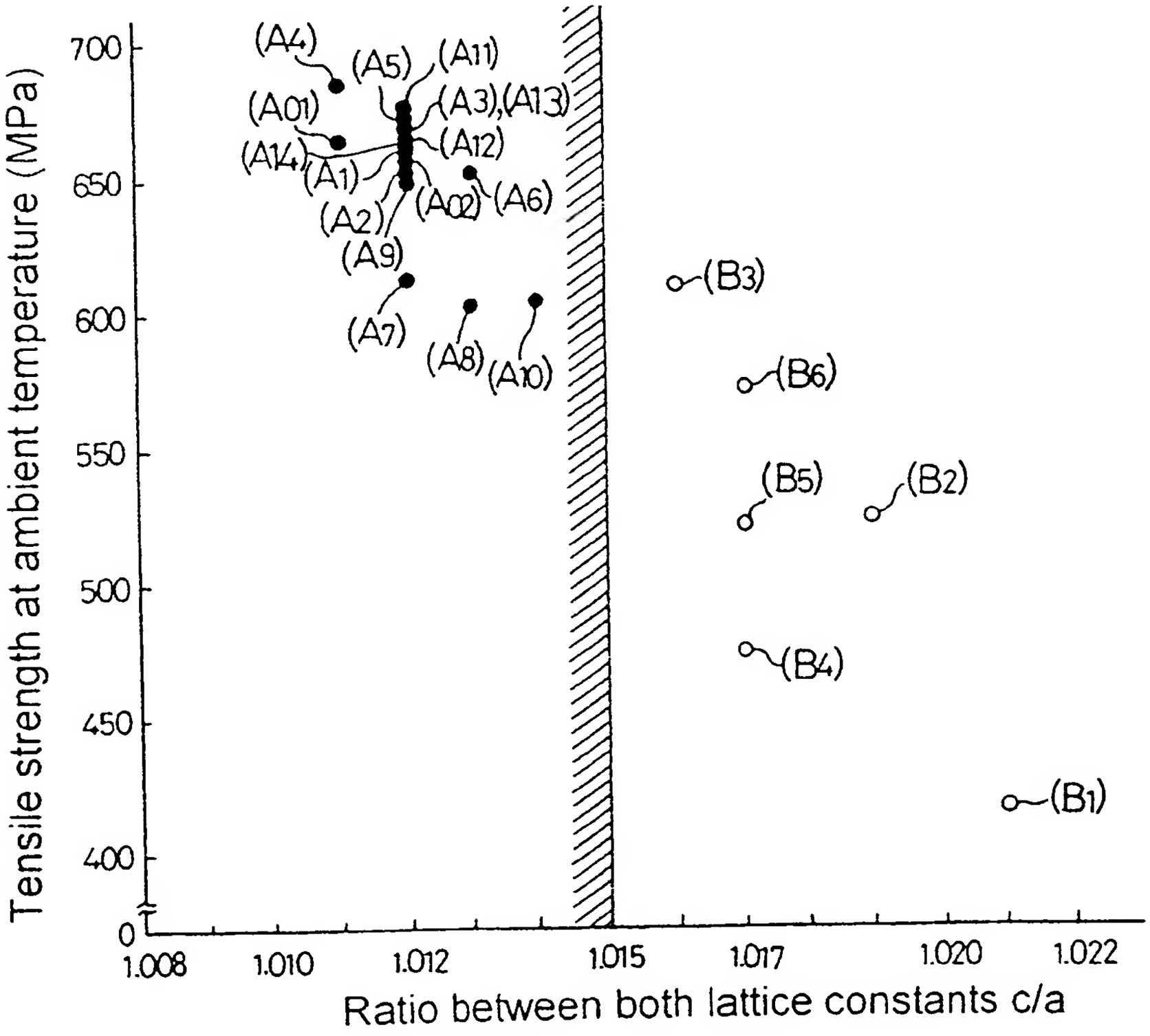

□ γ phase (TiAl phase)
○ α2 phase (Ti3Al phase)
(200)
(002)
60.0
50.0
40.0
30.0
20.0
10.0
2θ
I (cps)

FIG.3


Tensile strength at ambient temperature (MPa)
700
650
600
550
500
450
400
0
1.008
1.010
1.012
1.015
1.017
1.020
1.022
Ratio between both lattice constants c/a
(A4)
(A5)
(A11)
(A01)
(A3),(A13)
(A14)
(A12)
(A1)
(A2)
(A02)
(A6)
(A9)
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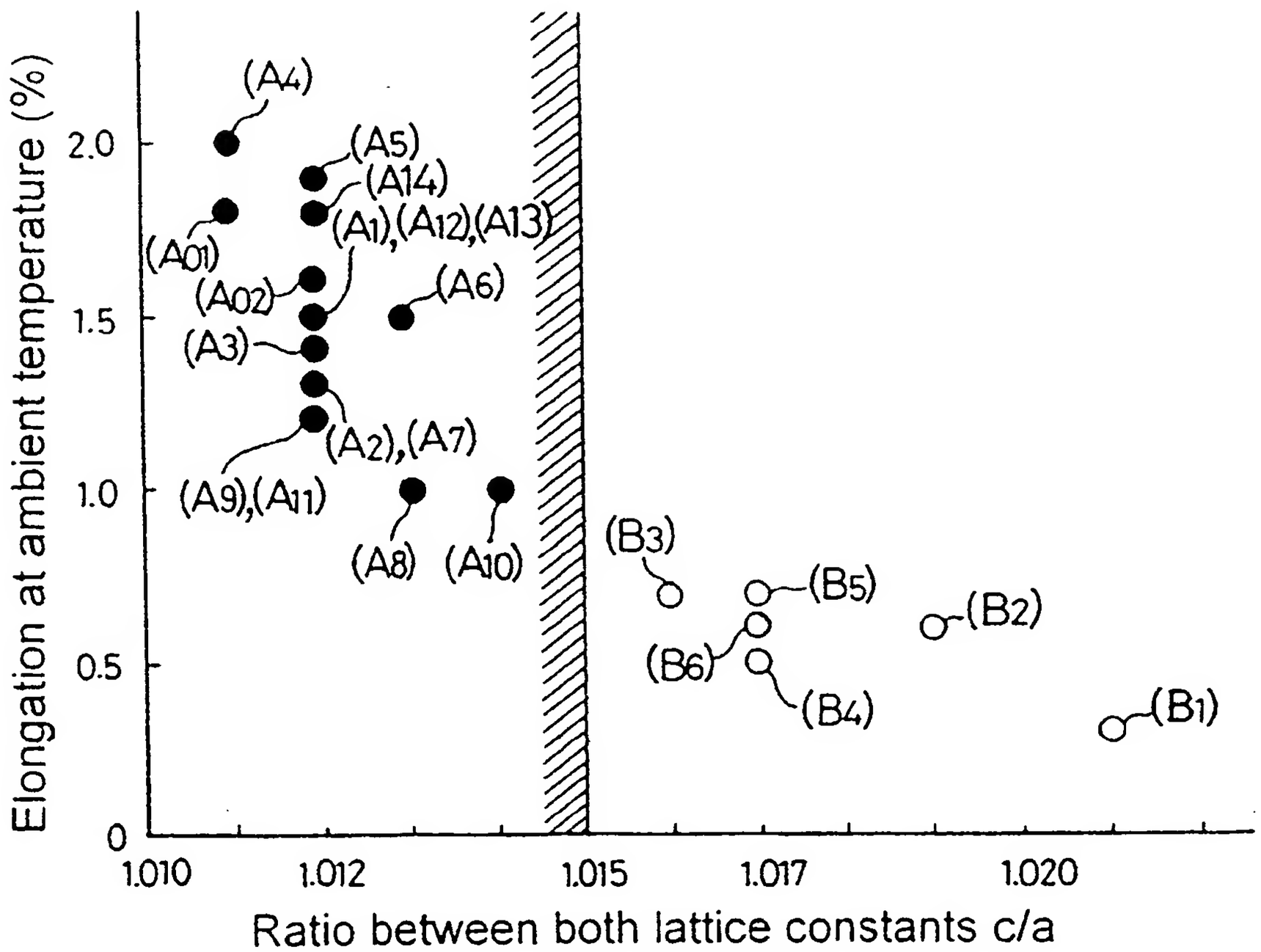
(B5)
(B2)
(B4)
(B1)

FIG.4


Elongation at ambient temperature (%)
2.0
1.5
1.0
0.5
0
(A4)
(A5)
(A14)
(A1),(A12),(A13)
(A01)
(A02)
(A6)
(A3)
(A2),(A7)
(A9),(A11)
(A8)
(A10)
(B3)
(B5)
(B2)
(B6)
(B4)
(B1)
1.010
1.012
1.015
1.017
1.020
Ratio between both lattice constants c/a

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 11 0899

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	EP-A-0 477 559 (GENERAL ELECTRIC COMPANY) 1 April 1992 * Claim 1; page 17, lines 1-3 and 21-32; Table VI * ---	1-5	C22C14/00
Y	US-A-4 857 268 (GENERAL ELECTRIC COMPANY) 15 August 1989 * Claim 1; Table III; Col.8, lines 5-8 * ---	1-5	
Y	EP-A-0 495 454 (SUMITOMO LIGHT METAL INDUSTRIES) 22 July 1992 * Claims 1 and 3; page 2, line 49 - page 3, line 3; Examples 5 and 7; page 6, lines 35-38 * ---	1-5	
A	US-B-4 842 820 (GENERAL ELECTRIC COMPANY) 12 May 1992 * Claim 10; Table IV * ---	1-5	
A,P	EP-A-0 581 204 (ABB PATENT) 2 February 1994 * Col.2, lines 12-18 and lines 37-45; Col.3, lines 18-20 * ---	1-5	TECHNICAL FIELDS SEARCHED (Int.Cl.6) C22C
A,D	PATENT ABSTRACTS OF JAPAN vol. 014, no. 080 (C-0689)15 February 1990 & JP-A-01 298 127 (SUMITOMO METAL IND) 1 December 1989 * abstract * ---	1-5	

-/--

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	4 November 1994	Pivalica-Bjoerk, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

Application Number
EP 94 11 0899

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	METALLURGICAL TRANSACTIONS A. PHYSICAL METALLURGY AND MATERIALS SCIENCE vol. 22A, no. 9 , September 1991 , NEW YORK US pages 2021 - 2029 CHAN K.S. 'MECHANICS OF SHEAR LIGAMENT TOUGHENING' * Pages 2026 - 2027 "Application to Titanium Aluminide Alloys" * -----	1-5	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	4 November 1994	Pivalica-Bjoerk, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

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L : document cited for other reasons

& : member of the same patent family, corresponding document

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